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# AIR FORCE RESEARCH LABORATORY

## ADVANCED UMV OPERATOR INTERFACES

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A head-mounted display (HMD) presents real video imagery or synthetically generated visual imagery via a head-mounted optic system with very small displays attached to a helmet, visor, or set of spectacles (see Figure 1). There is a wide range of technologies and approaches associated with today's HMD systems, including the type and quality of image display, monocular versus bi-ocular design, the ability to display color images, the ability to effectively display stereoscopic three dimensional (3D) images, system size/weight, and the ability to concurrently view the local external environment.

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# Chapter 3 – ADVANCED UMV OPERATOR INTERFACES

## 1.1 Data Display Systems

### 1.1.1 Head-mounted Displays

#### 1.1.1.1 Description of Technology

A head-mounted display (HMD) presents real video imagery or synthetically generated visual imagery via a head-mounted optic system with very small displays attached to a helmet, visor, or set of spectacles (see Figure 1). There is a wide range of technologies and approaches associated with today's HMD systems, including the type and quality of image display, monocular versus bi-ocular design, the ability to display color images, the ability to effectively display stereoscopic three dimensional (3D) images, system size/weight, and the ability to concurrently view the local external environment. As this section is intended primarily as a short summary of the HMD technology and its relevance to UMVs, interested readers should refer to [1][2][3] for more comprehensive coverage of this area.

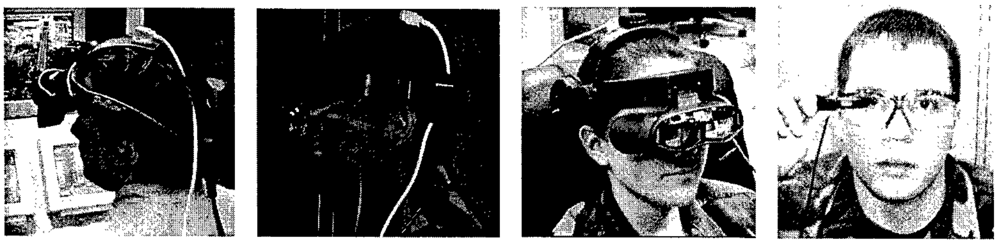

Figure 1. Examples of HMDs

HMDs can support either immersive or augmented reality applications, depending upon the transparency of the head-mounted optics. Immersive HMDs require the user to view only the image presented via the HMD optic system, while augmented reality HMDs allow the user to "see-through" the HMD display, thus combining imagery from the HMD with the surrounding real-world visual field. This section only considers immersive HMD display technology, i.e., designs that occlude the subject's view of his/her immediately surrounding physical environment. Augmented reality technology is discussed in section -------.

This section also only considers head-coupled HMD applications (i.e., the HMD visual image is updated in response to head movements, via a position tracking sensor that provides the computer with the current head location/orientation information). Head-coupled HMDs enable a synthetically generated visual scene to be continually modified in response to head movements so that, no matter how the user moves, objects in the viewed scene appear to remain in stable locations (thus providing the impression that the user is moving within the virtually generated space). Alternatively, in teleoperated robotic systems, the motion of the user's head can be used to control the position/orientation of a remote camera (or other robotic action) [4]. Head-coupled HMDs offer the highest potential degree of immersiveness and maximum utility. However there remain many limitations due to existing technology, as will be discussed below.

Depending upon the particular UMV application, it may be critical for a HMD to convey accurate depth information in an intuitive and accurate manner. Although all HMDs can convey a sense of depth and distance using conventional two-dimensional depth cues (including linear perspective, interposition, relative size, texture gradients, etc.), certain HMDs also have the potential to portray depth via various stereoscopic techniques. Stereopsis can provide an intuitive, unambiguous cue for depth and it dominates most other depth cues. Dichoptic presentation involves using two monitors to portray a scene, one monitor per eye, each with it's appropriate viewpoint for that eye's position in space [5]. This method utilizes binocular fusion to yield stereopsis. Electronic shutter glasses use one monitor to present a stereoscopic image by providing two alternating views of a scene (corresponding to the viewpoint disparity between the two eyes), synchronized to the frame rate, such that one interleaved frame in each pair is presented to each eye [5]. Section ----- contains more information on various 3D display technologies.

#### 1.1.1.2 Actual or Potential Application to UMVs

HMDs have been found to enhance wide-area search and intercept operations performed by manned aircraft [6]. A potential advantage of head-coupled control versus manual control over one's viewpoint is the addition of ecologically relevant proprioceptive cues which provide motion information based on vestibular inputs, joint angles, muscle lengths, and tendon tension during head movements. Head-coupled HMDs are also hypothesized to reduce cognitive processing demands in achieving new viewpoints. Some studies have suggested that head-coupled configurations facilitate awareness of areas already searched, thereby potentially reducing the re-scanning of those same areas [7]. Thus, HMD technology may benefit UMV operators, especially since reduced situational awareness is often a by-product of current UMV control station designs [8][9]. It is theorized that a HMD could enhance the operator's large-area searches and overall spatial orientation of the remote environment, while larger, high-resolution fixed console displays could be reserved for any target fine discrimination tasks. Other expected advantages of HMDs include hands-free control and intuitive operation. However, studies investigating the benefits of HMDs have so far produced mixed results. Below is a summary of the recent research in the area, categorized by type of UMV: UAV, UGV and UUV.

##### *1.1.1.2.1 UAVs*

HMDs have been demonstrated to have a positive impact of certain UAV control tasks. A study [10] explored UAV operator control of a remotely-operated helicopter using an omni-directional camera controlled by a head-coupled HMD. The HMD system was found to promote operator immersion in the vehicle, encouraging a feeling of presence as though the operator was in the vehicle. The HMD also resulted in faster and more accurate completion times in a simulated helicopter control task, compared to the alternative of attempting to control the helicopter while viewing it directly from the ground. These results support claims that HMDs can provide increased situation awareness. However, the non-HMD condition was somewhat lacking in that it did not include a fixed-display out-the-window view from the helicopter, so it is unclear whether viewpoint location or head-coupled HMD provided the observed improvements. Another study [11] explored HMDs for small UAV applications. The task involved piloting a small UAV past a ground target and then turning around at various distances to re-acquire that same ground target. The researchers found that the use of a head-coupled HMD resulted in faster and more successful re-acquisition of the ground target than when using a conventional display of imagery from the UAV's nose-camera. However the horizontal field-of view was nearly twice as large for the HMD as compared to the conventional display, which may have contributed to these findings. Additionally, all subjects complained of discomfort when wearing the HMD. Nonetheless, there does exist research support for the proposition that HMDs can provide greater situation awareness resulting in increased UAV operator performance.

An early experiment at the TNO Research Institute was conducted to explore the applicability of a head–slaved camera system in UMV applications [12]. To overcome some possible drawbacks of HMDs (e.g. weight), an HMD was compared with a head–slaved dome projection (Figure 2). To overcome the possible drawbacks of transmission delay, a method was introduced to compensate for the spatial distortions. This technique, called delay handling, preserves the correct spatial relation between the viewing direction of the camera and the operator, by presenting incoming images in the camera viewing direction at the moment the images were recorded, and not in the actual viewing direction of the operator. The results showed that delay handling is successful in supporting the perception of correct spatial relations. No differences in task performance were found between the actual HMD and the dome projection.

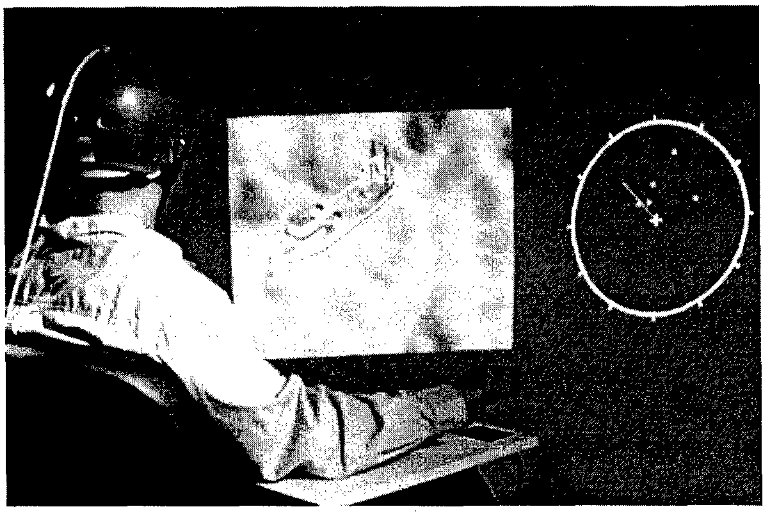

**Figure 2: Dome projection in which the camera direction is head–coupled, and the operator receives high quality proprioceptive feedback on camera viewing direction.**

In follow-on studies at TNO, researchers compared operator performance with head–coupled camera control, and Head Mounted Displays (HMDs) with manual camera control [13, 14]. Subjects had to locate targets as fast as possible. The results showed that head–slaved camera control increased search speed but enlarged the search path as compared to manual (joystick) control. An increased susceptibility, during head–slaved control, to mismatches between visual information and proprioceptive information may account for these findings. Additional measures of head movements showed that eye–head coordination was altered during head–slaved camera control. Since in these experiments, proprioceptive feedback was available in the manual control condition as well (the images were presented on a projection screen under the correct camera viewing direction), the findings imply an additional advantage of head–slaved control compared with manual control without proprioceptive feedback (as would be the case when using a fixed monitor). However, [15] found that employing simulated HMD images projected onto a large screen resulted in higher UAV operator performance than when they used an actual HMD, and [16] found that use of a conventional joystick for UAV control resulted in better performance than the head-coupled HMD. These latter results converge with several other studies, as detailed below.

Two experiments were conducted at AFRL to evaluate the usefulness of HMDs for UAV tasks involving the search for ground targets (Figure 3) [17, 18]. The overall approach was to compare the utility of a manual joystick with the associated stationary display monitor (the Baseline Condition) to that of various head-coupled HMD configurations. Specifically, gimbal camera orientation (azimuth and elevation angle) was controlled via either a right-hand control stick or head-coupled HMD, while camera zoom was always controlled with the left-hand forward/aft stick. In one study [17], the task involved conducting a wide area search followed by a target identification task. The wide-area search was conducted by using the baseline configuration (control stick and stationary display monitor) or a head-coupled HMD. The target identification task was always conducted using the higher resolution stationary display monitor, as the HMD did not have the required resolution to afford fine discrimination. Thus, in the HMD conditions, there was a need to switch between displays between search and identification tasks. The results failed to show any benefit for HMD-based configurations. Search time was shorter and workload was lower with the Baseline Condition than any of the HMD conditions. Additionally, many subjects experienced discomfort and simulator sickness symptoms with the HMD configuration.

Figure 2. UAV Workstation with Head-coupled HMD and Stationary CRT Camera Displays.

A follow-on study [18] was conducted to specifically evaluate the utility of a head-coupled HMD for the SO's conduct of a 360-degree large area search for multiple ground targets. This study did not include the additional target identification step that had required a switch from HMD to a stationary display in the previous study. Six camera control/display configurations were evaluated; two involved the stationary display monitor (each with a different rate gain joystick) and four involved a HMD. The four HMD configurations varied in the degree to which the camera moved with head movements. One "hybrid" configuration was also evaluated whereby the gimballed camera orientation could be controlled with both the head and the joystick simultaneously. Results indicated fewer unique targets were prosecuted with the HMD than with the fixed display monitor. Head-coupled control also resulted in more duplicate target designations, higher rated workload, and lower situation awareness ratings. These results suggest that there is no clear advantage for head-coupled HMDs in the performance of large-area search tasks. In fact, performance significantly decreased in some experimental manipulations involving the HMD.

A similar set of studies were conducted utilizing a simulation of a smaller UAV [19, 20]. One study compared a conventional display monitor to a HMD for target search, discrimination and designation tasks [19]. Although there were no differences between display conditions for target detection accuracy, the conventional display condition enabled more targets to be correctly identified from further away and allowed for more accurate cursor designation of those targets. Additionally, subjects experienced far more discomfort (e.g., nausea, disorientation, eyestrain) with the HMD condition. In a follow-on study [20], these researchers explored the effect of including various auditory cues (mono, stereo, 3-D spatialized) to the ground target location with the comparison of visual display conditions (conventional, head-coupled HMD). The results confirmed earlier findings that conventional displays resulted in significantly more precise target designations and fewer reports of discomfort. However, although HMD conditions yielded higher operator workload ratings then conventional displays across all conditions, 3-D spatialized cueing reduced HMD workload levels significantly.

*1.1.1.2.2 UGVs*

Designers argue that HMDs have characteristics that potentially offer many advantages over conventional UGV operator control units [21]. Advantages identified included the system's light weight, decreased power consumption, daylight readability, and theorized improvements in operator SA and telepresence. HMDs have also been demonstrated in UGV systems. HMDs were found to be beneficial during a demonstration of the feasibility of utilizing a dune buggy as a UGV travelling complex terrain [22]. Other researchers conducted a study which found telepresence, created from use of stereo TV imagery displayed in an HMD, permitted operators' to drive UGVs at higher speeds and on steeper side slopes by providing an enhanced sense of spatial / geographic awareness [23]. There has also been implementation of HMDs into operational UGV systems. Man-portable UGVs are completing missions in current military operations with operators who wear monocular HMDs [24]. Soldiers are successfully controlling the UGVs with a portable joystick and HMD to explore cave complexes and suspected enemy compounds. Packbots' success in combat environments demonstrate HMDs' increasing and promising role in UGV control station design.

*1.1.1.2.3 UUVs*

Although few studies have been conducted in this area, the potential value of HMDs to UUV systems seems promising from underwater operations to operator training because of HMDs' capability of providing a visually compelling sense of realism [25][26]. Other researchers have described the potential importance of providing UUV operators with meaningful cues for SA, good workspace visibility, and vehicle behaviour feedback for effective performance [27]. The testbed they designed to address underwater telerobotics included a head-coupled HMD option. Though research specifically addressing HMDs' effectiveness compared to other systems in operating UUVs is minimal, the difficulties for operators controlling UAVs and UGVs are similar to those in underwater vehicles, so it is reasonable to assume that research on HMDs in these systems could transfer to UUVs.

### 1.1.1.3 Research Challenges

HMDs have improved considerably since they were first introduced into the commercial market. However, there is still much research needed before they achieve widespread appeal in military and consumer applications. Research areas discussed below include ergonomic issues, resolution, time latencies, field of view, and the occurrence of motion-sickness type symptoms.

Ergonomic Issues

Ergonomic issues associated with HMDs can be primarily attributed to anthropometric, biomechanic, and psychomotor concerns. Most HMDs involve some encumbrance by the user, though this varies with particular equipment chosen. Lack of fit is a primary complaint of users [28]. This includes inappropriate fit, movement limitations, excessive weight and/or size, improper distribution of the weight. HMD weight also has the potential to alter eye–head coordination. Suggestions exist for improving fit [28]. Newer displays are being developed to minimize size and weight such that they can be clipped onto existing eye-pieces, although other tradeoffs exist (limited resolution, small field-of-view, display placement within larger visual field, etc.). Furthermore, certain HMDs enable the display system to be removed or rotated out of the way to afford intermittent HMD use within a larger real-world work task. However it is unknown which method is most preferable for various UMV applications. Additional information regarding ergonomic issues can be found elsewhere [1][3][4]. Much research is needed to improve the many ergonomic issues of HMDS.

Spatial Resolution

Spatial resolution is a measure of the level of detail available in a visual display [2]. However, it can be a misrepresented parameter in HMD specifications. Often, resolution is described in terms of number of pixels in a display. However, the size of the display and its distance from the observer also contribute to the effective resolution. Increasing display field-of-view (FOV) reduces effective resolution by enlarging each pixel in the same manner. Therefore a more effective manner in which to specify resolution is in terms of visual angle subtended per pixel, termed 'angular resolution'. Angular resolution is poor in most current HMDs, far lower then the resolving capability of the human eye (approximately 1 arcmin visual angle or less [2]). Thus researchers have found resolution to be a limiting factor in HMD utilization [29]. An additional confusion with assessing spatial resolution of color HMDs is associated with the pixel-type used for determining angular resolution. Color display pixels are often formed by grouping 3 or 4 monocular pixels of different wavelengths (such as red, green, blue). Display manufacturers often report the number of pixels and angular resolution based upon the total number of monocular pixels available instead of available color pixels.

Research is needed to better define spatial resolution requirements of HMDs for the range of envisioned UMV tasks. Additionally, research is needed to improve spatial resolution. One promising technology in this area is the virtual retinal display [30].

Time Latencies

Time delays exist between movements made by the user's head (which are tracked by some position-sensing device) and the response of the HMD scene to those movements, due to delays in position tracking and image generation [4]. Time delays between head movements and virtual image response result in loss of visual stability which can affect task performance and generate a sensory rearrangement between visual and vestibular cues of motion. These sensory rearrangements are believed to induce simulator sickness symptoms [31, 32, 33]. When the additional time delay associated with UMV datalink communications are factored in, the total delay can be on the order of several seconds. Additionally, time delays can affect user acceptance [7].

Specifications are needed for acceptable HMD time delay for various UMV applications, factoring in the delays associated with communication with the vehicle. Acceptable time delays for UUV operations may not be acceptable for fast-moving UAV systems. Research is also needed on methods to ameliorate the effects of time delay, such as through the use of prediction techniques for head motion.

Display Field-of-View (DFOV)

DFOV is the visual angle subtended by the display screen from a given observer location [34]. This parameter, described in terms of its horizontal and vertical components, is often desired to be large to promote a sense of immersiveness (i.e., presence) and to improve task performance through the utilization of peripheral vision (limited DFOV displays result in the development of different scanning strategies). However, a tradeoff that occurs when one tries to increase DFOV using an existing display is a corresponding reduction of screen resolution. Given a fixed display size, the only way to increase DFOV is to either magnify the display using optics or move the eye closer to the screen. In either case, pixel size increases in the same proportion as screen size (since both are fixed values). As pixel sizes increase, display resolution decreases. Research is needed to better understand DFOV requirements for various UMV applications.

Additionally, the relation between DFOV and geometric FOV (zoomed in or zoomed out images) and its effect on UMV operator performance and comfort is needed [34].

Simulator Sickness/Cyber Sickness

Simulator sickness (also termed cyber sickness) is a form of motion sickness that occurs as a result of experiencing computer-simulated visual environments [34]. Symptoms include nausea, fatigue, headache, eye-strain, dizziness, malaise, and blurred vision. Besides the deleterious effects associated with simulator sickness, experiencing these symptoms may result in reduced desire to interact with the provoking system in the future, thus potentially hampering overall mission effectiveness. HMD usage has been strongly linked with increased levels of simulator sickness in many studies including those involving UMVs [17][19][20]. Although some guidelines exist, more research is needed to fully characterize and alleviate simulator sickness in UMV-related HMD applications.

Other Issues

Other research issues include the need to better understand and mitigate workload associated with HMD usage. Due to ergonomic concerns as well as the need to constantly move one's head to change one's viewpoint, workload and fatigue are real concerns associated with this technology [19] and mitigation techniques must be explored [18]. Head tracking technology and research is also needed to define minimum accuracy requirements for various UMV systems and to enable unencumbered operations [35]. Display brightness and contrast are also issues, especially for applications in outdoor environments.

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